Fermilab

Particle Physics Division

Mechanical Department Engineering Note

Number: MD-ENG-266 Date: 8/03/2010

Project Internal References: none

Project: DECAM

Title: Monsoon Crate Cooling System Test Results: 7/30/2010

Author(s): Matthew L. Alvarez

Reviewer(s): Herman Cease

Key Words:

Abstract Summary: Results of July 30, 2010 Monsoon Crate Cooling System test are contained in this document. Two of the three crates were powered on at the time of the test. Temperatures and pressures were measured using thermocouples and pressure indicators. The test pump work W, process side , and the facility side flow rate were calculated. Lastly, a thermal model was created to simulate a test for four monsoon crates.

Applicable Code: none

Monsoon Crate Cooling System Test Results: 7/30/2010

Matthew Alvarez- FNAL

Originally written on *8/02/2010* for the first time

INTRODUCTION

The Monsoon Crate Cooling System (MCCS) has been setup in Lab A using only three monsoon crates. The system was recently purged and was operating at around 60psi @ 3gpm for the three crates. The fluids used are 30% propylene glycol and 40% ethylene glycol on the process and the facility sides. Previous calculations were made using EES and using four monsoon crates. The following figure shows the expected values for four crates.

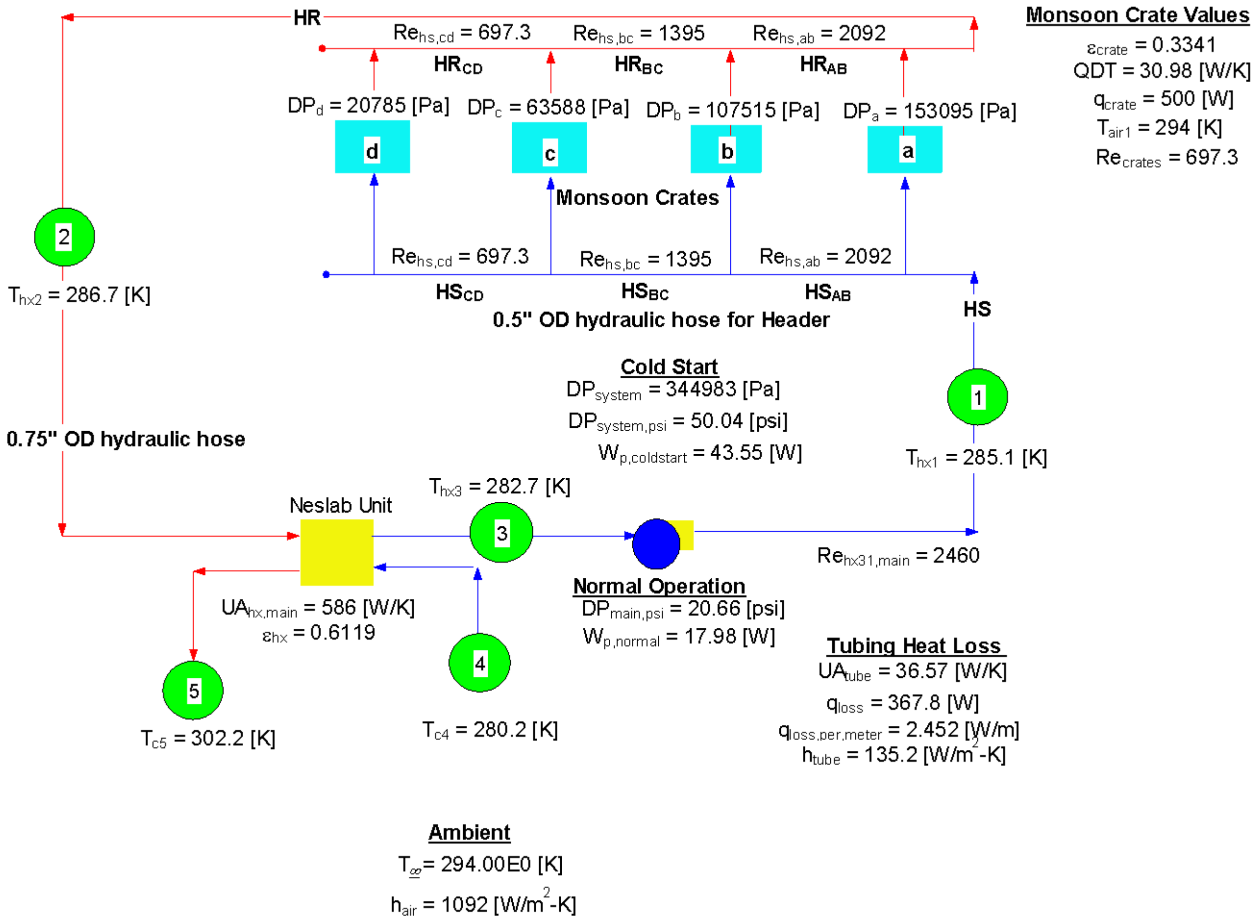


Figure 1: MCCS 4 Crate Simulation[1]

Once the system was bled of trapped air, the various temperatures and pressures were recorded. The measured parameters will help determine the heat removed by the system, the Neslab System I efficiency, and the mass flow rate of the facility side.

[1] The thermal model predicts the temperature, pressures, etc., given a flow rate of 2gpm.

EQUATIONS

The dynamic viscosities, thermal conductivities, densities, and specific heats were calculated using curve fit equations derived from *Ethylene and Propylene glycol Fluid and Thermal Properties: 4623-v2.* The Neslab System I is a counterflow heat exchanger and the following equation was used to determine its efficiency. Variables are described in the ***APPENDIX***.

$$\varepsilon_{hx} = \frac{q_{process}}{q_{max}}$$

$$C_{min} = \mathbf{Min}\left(m_{hx} \cdot cp_{hx12} \ , \ m_c \cdot cp_{c45} \right)$$

$$C_{max} = \mathbf{Max}\left(m_{hx} \cdot cp_{hx12} \ , \ m_c \cdot cp_{c45} \right)$$

$$q_{process} = C_{max} \cdot \left(T_2 - T_1 \right)$$

$$NTU_{hx} = \frac{UA_{hx}}{C_{min}}$$

$$NTU_{hx} = \left[\frac{1}{C_r - 1} \right] \cdot \mathbf{ln}\left[\frac{\varepsilon_{hx} - 1}{\varepsilon_{hx} \cdot C_r - 1} \right]$$

$$q_{max} = C_{min} \cdot \left(T_2 - T_4 \right)$$

Eq. 1

The next equation is the performance curve equation from the Neslab System I heat exchanger. Using this performance curve requires that the facility side to have a temperature difference of at least 10ºC. Recall that the facility side should equal the process side heat rate.

$$q_{process} = 4.22677 \times 10^{7} \cdot \dot{V}_c - 666.667$$

Eq. 2

Finally, the pump power can be calculated using the following equation.

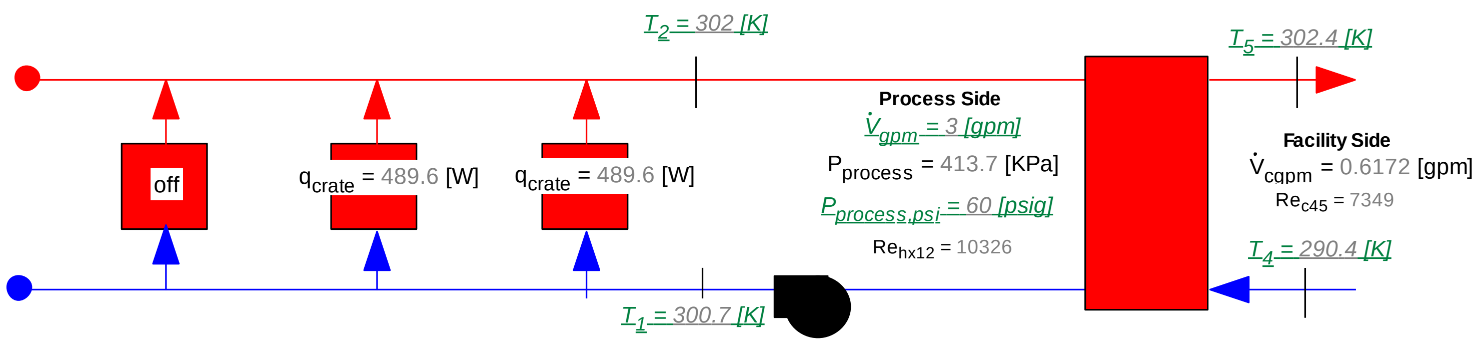
$$W_p = \frac{m_{hx}}{\rho_{hx12}} \cdot P_{process} \cdot 1000$$

Eq. 3

RESULTS

The two of the monsoon crates were installed and powered on. Flow through the monsoon crates was verified by measuring the pressure across a venturi meter. The variables in *green* were recorded using a pressure meter or a thermocouple. Notice that the third crate was not powered on for this test.

MONSOON CRATE COOLING SYSTEM TEST JULY 30, 2010
PROCESS SIDE: 30 % PROPYLENE GLYCOL
FACILITY SIDE: 40% ETHYLENE GLYCOL



NESLAB SYSTEM I

$q_{process} = 979.1$ [W]
$q_{max} = 1656$ [W]
$UA_{hx} = 136.6$ [W/K]
$\varepsilon_{hx} = 0.5912$
$W_p = 78.3$ [W]

$\mu_{water} = 0.0008293$ [N-s/m^2]	$k_{water} = 0.6001$ [W/m-K]	$\rho_{water} = 996.2$ [kg/m^3]	$cp_{water} = 4183$ [J/kg-K]
$\mu_{hx12} = 0.001661$ [N-s/m^2]	$k_{hx12} = 0.4659$ [W/m-K]	$\rho_{hx12} = 1025$ [kg/m^3]	$cp_{hx12} = 3883$ [J/kg-K]
$\mu_{c45} = 0.0004599$		$\rho_{c45} = 1003$ [kg/m^3]	$cp_{c45} = 3656$ [J/kg-K]

$A_{hx} = 0.00007238$ [m^2]	$cp_{c45} = 3656$ [J/kg-K]	$cp_{hx12} = 3883$ [J/kg-K]	$cp_{water} = 4183$ [J/kg-K]	$C_{max} = 753.2$ [W/K]
$C_{min} = 142.8$ [W/K]	$C_r = 0.1896$	$DP_{chiller} = 58.61$ [kPa]	$DP_{chiller,\psi} = 8.5$ [psid]	$\varepsilon_{hx} = 0.5912$
$ID_{tube,process} = 0.0096$ [m]	$k_{hx12} = 0.4659$ [W/m-K]	$k_{water} = 0.6001$ [W/m-K]	$\mu_{c45} = 0.0004599$	$\mu_{hx12} = 0.001661$ [N-s/m^2]
$\mu_{water} = 0.0008293$ [N-s/m^2]	$m_c = 0.03905$ [kg/s]	$m_{hx} = 0.1939$ [kg/s]	$NTU_{hx} = 0.9571$	$n_{crates} = 2$
$OD_{tube,process} = 0.0127$ [m]	$P_{process} = 413.7$ [KPa]	$P_{process,\psi} = 60$ [psig]	$P_{water} = 35$ [kPa]	$q_{crate} = 489.6$ [W]
$q_{max} = 1656$ [W]	$q_{process} = 979.1$ [W]	$Re_{c45} = 11024$	$Re_{hx12} = 15489$	$\rho_{c45} = 1003$ [kg/m^3]
$\rho_{hx12} = 1025$ [kg/m^3]	$\rho_{water} = 996.2$ [kg/m^3]	$T_1 = 300.7$ [K]	$T_{12avg} = 301.4$ [K]	$T_2 = 302$ [K]
$T_4 = 290.4$ [K]	$T_5 = 302.4$ [K]	$T_{c45avg} = 296.4$ [K]	$UA_{hx} = 136.6$ [W/K]	$V_c = 0.5265$ [m\s]
$\dot{V}_c = 0.00003894$ [m^3/s]	$\dot{V}_{cgpm} = 0.6172$ [gpm]	$\dot{V}_{gpm} = 3$ [gpm]	$\dot{V}_{hx} = 0.0001893$ [m^3/s]	$V_{hx} = 2.615$ [m\s]
$W_p = 78.3$ [W]				

Figure 2: Monsoon Crate Cooling System Test July 30, 2010

DISCUSSION

The MCCS test results indicate a Neslab System I heat effectiveness of ~60%. The control valve on the Neslab unit regulated the flow rate on the facility side to 0.61 gpm. Also, notice that each crate was outputting nearly 489.6W of the total 600W specification. The system pressure is relatively high~60psid, but below the relief valve pressures of 80 psid. Therefore, the current model in Lab A functions effectively for normal operation in Cerro Tololo Inter-American Observatory (CTIO).

FUTURE RECOMMENDATIONS

It would be best to adjust the flow meter on the process side so that each crate receives 0.5 gpm, which match the specifications in *Crate Heat Exchanger Unit Specifications: 3819-v3*. If the system pressure is 60psid for three crates in parallel, then adding an additional crate to the system should not affect the pressure drop so much.

Test Prediction for 4x the Monsoon Crates

The thermal model, *Figure 3*, uses the test data as a basis for predicting pressures, flow rates, fluid and thermal properties. Once all the crates are connected and powered on, the thermal model should be capable of predicting pressures, flow rates, and temperatures within an order of magnitude.

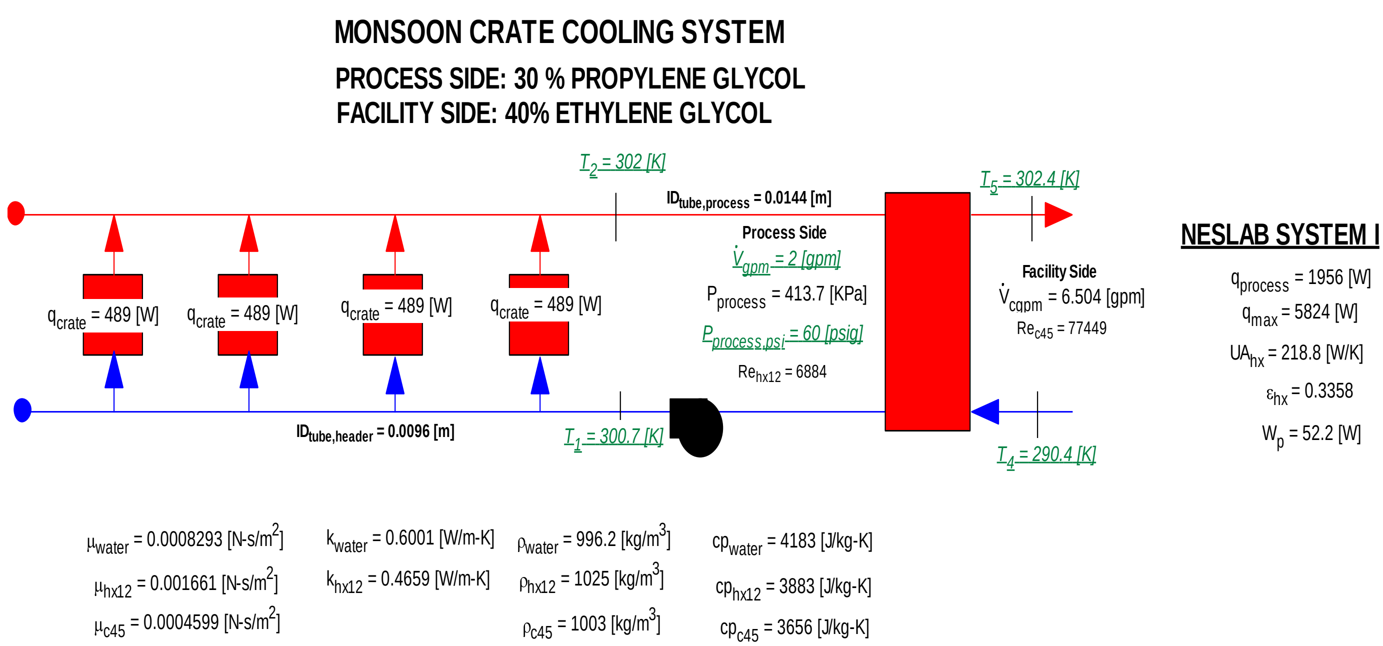


Figure 3: 4x Monsoon Crates Parameter Prediction

It is expected that the monsoon crates will output ~500W. Given the recorded process side flow rate, pressures, and temperatures measured from the test on Friday July 30, the facility side flow rate should adjust to 6.5 gpm. This change occurs to compensate for the fixed temperatures and pressures assigned to the simulated test.

Pumping Glycol to the Top of the Telescope ~65 ft or 20 m.

It is possible that the pressure during a cold start may exceed the system relief valve pressure, ~80psig. The pressure added to drive a column of propylene glycol vertically for 65 ft is ~30psig. The Neslab system I is preset to operate at a system pressure of 55 psig and higher. Therefore, after adding the cold start pressure to the normal operation of the Neslab unit, the total system pressure is at least 85 psig, which will trigger the relief valve in the Neslab unit and the system. (1032 kg/m^3*9.81 m/s^2*20 m*0.0001450 (lb/in^2)/(N/m^2)=29.3 psi)

APPENDIX

Variable Descriptions

A_hx- cross sectional area of tubing [m^2] cp_#- specific heat of # [J/kg-K] C_max- maximum heat capacitance [W/K] C_min- minimum heat capacitance [W/K] C_r- ratio of C_min to C_max DP_chiller- chiller pressure drop [kPa] epsilon_hx- Neslab System I efficiency ID_tube_process- inside diameter of 1120 Nylon Air Brake Tubing [m] k_hx12- Thermal Conductivity [W/m-K] mu_# - Dynamic Viscosity [N-s/m^2] m_c- facility side mass flowrate [kg/s] m_hx- process side flowrate[kg/s] NTU_hx- number of heat transfer units	n_crates- number of crates OD_tube_process- outside diameter of the 1120 Nylon Air Brake Tubing [m] P_process- Process side pressure [kPa] q_crate- heat rate of one crate[W] q_max- Neslab theoretical heat rate [W] q_process- Neslab experimental heat rate [W] Re_#- Reynolds number rho_#- density of the fluid [kg/m^3] T_#- temperature at point # [K] T_#avg- average temperature at # [K] UA_hx- overall heat transfer coefficient[W/K] V_#= velocity of fluid [m\s] V_dot_c- volumetric flowrate [m^3/s] W_p- pumping power [W]

Written Code: July 30, 2010 Test, 2x Monsoon Crates

```
//Friday July 30, 2010
//J, K, kPa
//recorded temperatures
T_2=29+273
T_1=27.7+273
T_4=17.4+273
T_5=29.4+273

n_crates=2 {2 of the crates were operating at capacity}
//flow rate
V_dot_gpm=3
V_dot_hx=V_dot_gpm*6.30901964E-5
//Facility flow rate
V_dot_c=V_dot_cgpm*6.30901964E-5

//Pressures
P_water=35
DP_chiller_psi=8.5 {psid}
DP_chiller=DP_chiller_psi*6.89475
P_process_psi=60 {psig}
P_process=P_process_psi*6.8947
//Neslab Curve Fit Eq.
q_process = 42267659.957*V_dot_c - 666.667

//tubing dimensions
ID_tube_process=0.0096
OD_tube_process=0.0127
A_hx=pi*ID_tube_process^2/4

//Properties of Propylene and Ethylene Glycol
//Average Temperatures
T_12avg=(T_1+T_2)/2
T_c45avg=(T_4+T_5)/2

//Specific Heat Capacity
{30% Propylene Glycol}
```

```
cp_hx12=(0.0028*(T_12avg-273)+3.8041)*1000
cp_water=Cp(Water,T=T_12avg,P=P_water)
{40% Ethylene Glycol}
cp_c45= 2.6226*(T_c45avg-273)+ 3594.7


// Density
{30% Propylene Glycol}
rho_hx12=-0.0026*(T_12avg-273)^2-0.3292*(T_12avg-273) +1036.1
rho_water=density(water, T=T_12avg, P=P_water)
{40% Ethylene Glycol}
rho_c45= 3E-07*(T_c45avg-273)^4 - 1E-04*(T_c45avg-273)^3 + 0.0128*(T_c45avg-273)^2 - 0.0693*(T_c45avg-273) +
998.74

//thermal conductivity
{30% Propylene Glycol}
k_hx12=-3*10^(-6)*(T_12avg-273)^2+0.0001*(T_12avg-273)+0.4655
k_water=conductivity(water, T=T_12avg,P=P_water)

//Dynamic Viscosity
{30% Propylene Glycol}
mu_hx12=3*10^(-10)*(T_12avg-273)^4 - 8*10^(-8)*(T_12avg-273)^3+8*10^(-6)*(T_12avg-273)^2-0.0004*(T_12avg-
273)+0.0082
mu_water=viscosity(water, T=T_12avg,P=P_water)
{40% Ethylene Glycol}
mu_c45 = 2E-15*(T_c45avg-273)^6 - 1E-12*(T_c45avg-273)^5 + 3E-10*(T_c45avg-273)^4 - 4E-08*(T_c45avg-273)^3 +
2E-06*(T_c45avg-273)^2 - 9E-05*(T_c45avg-273) + 0.0019

//Mass Flow Rates
m_hx=V_dot_hx*rho_hx12
m_c=V_dot_c*rho_c45

//Velocities
V_hx=m_hx/(rho_hx12*A_hx)
V_c=m_c/(rho_hx12*A_hx)

//Heat Exchanger: Neslab Unit Calculations
C_min=min(m_hx*cp_hx12,m_c*cp_c45)
C_max=max(m_hx*cp_hx12,m_c*cp_c45)
q_process=C_max*(T_2-T_1)
q_max=C_min*(T_2-T_4)
epsilon_hx=q_process/q_max
C_r=C_min/C_max
NTU_hx=1/(C_r-1)*ln((epsilon_hx-1)/(epsilon_hx*C_r-1))
NTU_hx=UA_hx/C_min
q_crate=q_process/2

//Pumping Power
W_p=m_hx/rho_hx12*P_process*1000

//Reynolds numbers
Re_hx12=rho_hx12*V_hx*ID_tube_process/mu_hx12
Re_c45=rho_c45*V_c*ID_tube_process/mu_c45
```

Written Code: Prediction for 4x Monsoon Crates

```
// lines of code changed from the test code above
n_crates=4
V_dot_gpm=2
q_process= 489*n_crates

ID_tube_process=0.0144
OD_tube_process=0.0191
A_hx=pi*ID_tube_process^2/4
ID_tube_header=0.0096
OD_tube_header=0.0127
A_hx_header=ID_tube_header^2*pi/4
```

$A_{hx} = 0.0001629$ [m^2]	$A_{hx,header} = 0.00007238$	$cp_{c45} = 3656$ [J/kg-K]	$cp_{hx12} = 3883$ [J/kg-K]	$cp_{water} = 4183$ [J/kg-K]
$C_{max} = 1505$ [W/K]	$C_{min} = 502.1$ [W/K]	$C_r = 0.3337$	$DP_{chiller} = 58.61$ [kPa]	$DP_{chiller,\psi} = 8.5$ [psid]
$\varepsilon_{hx} = 0.3358$	$ID_{tube,header} = 0.0096$ [m]	$ID_{tube,process} = 0.0144$ [m]	$k_{hx12} = 0.4659$ [W/m-K]	$k_{water} = 0.6001$ [W/m-K]
$\mu_{c45} = 0.0004599$ [N-s/m^2]	$\mu_{hx12} = 0.001661$ [N-s/m^2]	$\mu_{water} = 0.0008293$ [N-s/m^2]	$m_c = 0.4115$ [kg/s]	$m_{hx} = 0.1293$ [kg/s]
$NTU_{hx} = 0.4358$	$n_{crates} = 4$	$OD_{tube,header} = 0.0127$ [m]	$OD_{tube,process} = 0.0191$ [m]	$P_{process} = 413.7$ [KPa]
$P_{process,\psi} = 60$ [psig]	$P_{water} = 35$ [kPa]	$q_{crate} = 489$ [W]	$q_{max} = 5824$ [W]	$q_{process} = 1956$ [W]
$Re_{c45} = 77449$	$Re_{hx12} = 6884$	$\rho_{c45} = 1003$ [kg/m^3]	$\rho_{hx12} = 1025$ [kg/m^3]	$\rho_{water} = 996.2$ [kg/m^3]
$T_1 = 300.7$ [K]	$T_{12avg} = 301.4$ [K]	$T_2 = 302$ [K]	$T_4 = 290.4$ [K]	$T_5 = 302.4$ [K]
$T_{c45avg} = 296.4$ [K]	$UA_{hx} = 218.8$ [W/K]	$V_c = 2.466$ [m\s]	$\dot{V}_c = 0.0004103$ [m^3/s]	$\dot{V}_{cgpm} = 6.504$ [gpm]
$\dot{V}_{gpm} = 2$ [gpm]	$\dot{V}_{hx} = 0.0001262$ [m^3/s]	$V_{hx} = 0.7748$ [m\s]	$W_p = 52.2$ [W]	